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A Mineral Survey for Piezo-Electric Materials

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BECAUSE of the increasing interest in piezoelectric materials in many branches of science an exhaustive study of the minerals was undertaken with the object of finding all the materials that could possibly be of use for piezo-electric elements. Much help was derived from existing data.[1]

Considerations of symmetry show us that for a crystal to be piezo-electrically active it must belong to a crystal class that has no center of symmetry (the Pentagonalicositetredral class of the cubic system, however, although it has no center of symmetry cannot be piezo active).[2] This makes twenty classes of possible piezo activity and twelve classes that could not possibly be active. About 90% of the crystals found in nature fall in those classes having centers of symmetry.

Although the mineralogical data are incomplete in their assignment of minerals to definite classes in the seven systems, the existing data give a start in the choosing of minerals likely to have useful piezo-electric properties.

All available data were gone through to obtain the following list of minerals classified by crystal structures. As many of the non-centric ones as were obtainable in the United States were tested by the method of Geibe and Scheibe[3] (resonance in a thermionic oscillator circuit). Whenever the authorities differed on the classification of a mineral it was so examined if obtainable.

In the mineral list, each mineral is numbered according to the number of the class in Groth's Physikalische Kristallographie, as follows: (*) indicating classes of possible activity:

*1 Assymmetric
2 Pinacoidal } Triclinic system

[1] Dana—A System of Mineralogy, Ford—Dana's Textbook of Mineralogy; Groth—Chemische Kristalographie; Landölt Börnstein—Tabellen; International Critical Tables; Zeitschrift fur Kristalographie.

[2] W. Voigt, Kristal physik.

[3] *Zeits f Physik* 33, pg. 761 (1925).

*3 Sphenoidal
4 Domatic
5 Prismatic
} Monoclinic system

*6 Bisphenoidal
*7 Pyramidal
8 Bipyramidal
} Orthorhombic system

*9 Bisphenoidal
*10 Pyramidal
*11 Scalenohedral
*12 Trapezohedral
13 Bipyramidal
*14 Ditetragonal Pyramidal
15 Ditetragonal Bipyramidal
} Tetragonal system

*16 Pyramidal
17 Rhombohedral
*18 Trapezohedral
*19 Bipyramidal
*20 Ditrigonal pyramidal
21 Ditrigonal Scalenohedral
*22 Ditrigonal Bipyramidal
} Rhombohedral system

*23 Pyramidal
*24 Trapezohedral
25 Bipyramidal
*26 Dihexagonal Pyramidal
27 Dihexagonal Bipyramidal
} Hexagonal system

*28 Tetrahedral-Pentagonal-Dodecahedral
29 Pentagonal Icositetrahedral
30 Dyakis-Dodecahedral
*31 Hexakis-tetrahedral
32 Hexakis Octahedral
} Cubic system

In addition to the above classification, the following list of minerals is annotated with the following symbols:

A = active by test
I = inactive by test
R = unavailable or rare
M = mineral occurs only massive, amorphous or in other unsuitable form
S = crystal always very small
H = mineral is always non-homogeneous
U = unstable
C = electrically conducting
? = class not absolutely certain

CLASSIFIED LIST OF MINERALS

Actinolite	5	Allanite	5	Amosite	M
Adelite	5	Allemontite	21	Ampangabeite	8?UI
Aegirite	5?I	Allophane	M	Amphibole	5?HI
Aenigmatite	2	Almandite	32	Analcime	32
Aeschynite	8	Altaite	32	Ancylite	8
Alabandite	*31I	Aluminite	M	Andalusite	8
Alamosite	5	Alunite	21	Andesine	2
Albite	2	Alunogen	M	Andorite	8
Algondonite	H	Amblygonite	2	Andradite	32
Allactite	5?SI	Amesite	5	Anemousite	2

Anglesite	8	Bismite	21?I	Chillagite	10?
Anhydrite	8	Bismuthinite	8	Chloanthite	30
Ankerite	17	Bismutite	M	Chlorastrolite	H
Annabergite	5	Blödite	5	Chlorite	5
Annerodite	8	Blomstrandine	8?MI	Chloritoid	5
Anomite	5	Boleite	15?I	Chlormanganokalite	21
Anorthite	2	Boracite	*7A	Chloropal	M
Anorthoclase	2	Borax	5	Chloraphoenicite	I
Anthophyllite	8	Borickite	M	Chlorospinel	32
Antigorite	5?H	Bornite	*11I	Chondrodite	5
Antlerite	M	Boulangerite	8	Chromite	32
Apatite	25I	Bournonite	8	Chrysoberyll	8
Aphrosiderite	?I	Braunite	15	Chrysolite	8
Aphthitalite	21	Breithauptite	*20I	Cinnabar	*18I
Apophyllite	15	Britholite	27?S	Claudetite	5
Aragonite	8	Brochantite	8	Clausthalite	M
Ardennite	8	Bromyrite	32	Cleveite	32
Ardunite	M	Brookite	8	Clinochlor	5
Arfvedsonite	5	Brucite	21	Clinoclasite	5
Argentite	32	Brushite	5	Clinohedrite	*4A
Argentojarosite	I	Bunsenite	32	Clinohumite	5
Argyrodite	32	Bytownite	2	Clinozoisite	5
Arrhenite	H			Cobaltite	*28C
Arseniosiderite	8	Cabrerite	5	Cohenite	M
Arsonolite	32	Cacoxnite	M	Colemanite	5
Arsenophyrite	8	Calamine	*7A	Collinsite	I
Ascharite	M	Calaverite	5	Collophanite	M
Astrakanite	5	Calciothorite	M	Coloradoite	M
Astrophyllite	8?I	Calcite	2I	Columbite	8
Atacamite	8	Caledonite	8	Connellite	25
Auerlite	15	Calomel	I5	Cookeite	M
Augite	5I	Campylite	25	Cordylite	21
Aurichalcite	M	Cancrinite	27	Cornetite	?I
Automolite	32	Canfieldite	32	Corundum	21
Aventurine	2	Cannizzarite	?I	Corynite	28I
Axinite	2	Carnallite	8	Cotunnite	8
		Carnotite	I	Covellite	*18?I
Babingtonite	2	Carpholite	5	Crestmoreite	M
Baddeleyite	5	Caryocerite	21	Cristobalite	M
Baldaufite	?R	Cassiterite	15	Crocidolite	M
Barkevikite	5	Castorite	5	Crocoite	5
Barite	8	Caswellite	I	Cronstedtite	*16A
Barytocalcite	5	Catapleite	5	Crookesite	M
Bastnäsite	I	Celestite	8	Cryolite	5
Baumhauerite	5	Celsian	5	Cryolithionite	32
Bauxite	M	Cenosite	8?I	Cuprite	32
Beaverite	?S	Cerargyrite	32	Cuproscheelite	I
Bechilite	M	Cerite	8	Cyanite	2
Beckelite	32?S	Cerrusite	8	Cyrtolite	I
Bementite	8?I	Cervantite	8?		
Benitoite	*22I	Chabazite	2I?I	Dahllite	M
Beraunite	I	Chalcanthite	2	Danburite	8
Bertrandite	*7I	Chalcedony	8?M	Datolite	5
Beryl	27	Chalcocite	8	Dawsonite	M
Beryllonite	8	Chalcolamprite	32	Dechenite	8
Berzelianite	MR	Chalcophyllite	21?I	Delessite	?SI
Berzelite	32?I	Chalcopyrite	*11C	Dellafosite	I
Betafite	32	Chalcosiderite	2	Delorenzite	8
Bindheimite	M	Chalcostibite	8	Delvauxite	M
Binnite	32?I	Chamosite	M	Demantoid	32
Biotite	5	Chiastolite	8	Deschloizite	8
Bischofite	5	Childrenite	8?I	Desmine	5

Deweylite	M
Diamond	31?I
Diaphorite	8
Diaspore	8
Diopside	5
Dioptase	17
Dixenite	?SI
Dolemite	17
Domeykite	8
Douglasite	5
Dufrenite	8
Dufreneysite	5
Dumortierite	8
Dysanalyte	32
Dyscrasite	8
Edingtonite	*6A
Eleonorite	?R
Ellsworthite	MR
Elpidite	8
Embolite	32
Emerald	27
Emmonsite	?SI
Emplectite	8
Enargite	8
Enstatite	8
Eosphorite	8?HI
Epidesmine	8?SI
Epididymite	8
Epidote	5
Epistilbite	*4?A
Epistolite	5
Epsomite	*6A
Erikite	8
Erythrite	5
Erythrosiderite	8
Euclase	5
Euchroite	8?I
Eucolite	21
Eucairite	M
Eudialyte	21
Eudidylite	5
Eulytite	*31I
Euxenite	8
Fairfieldite	2
Fassaite	5
Faujasite	32
Fayalite	8
Ferberite	5
Fergusonite	*10I
Ferrierite	I
Florencite	21
Fluocerite	27
Fluorite	32
Forsterite	8
Forsbagite	M
Fouquerite	I
Fowlerite	2
Francolite	25
Franklinite	32
Freibergite	*31C
Freyalite	M
Frieseite	8
Fritzscheite	15
Fucbsite	I
Gadolinite	5
Gageite	I
Gahnite	32
Galena	32
Ganomalite	I
Garnet	32
Gastaldite	5
Gay-Lussite	5
Gedrite	8
Gehlenite	15
Germantite	32
Gersdorffite	30
Geyserite	M
Gilsonite	M
Gismondite	5
Glaserite	21
Glauberite	5
Glaucodot	8
Glauconite	M
Glaucopbane	5
Gmelinite	17
Goethite	8
Goslarite	*6I
Graphite	21
Greenockite	*20IS
Griffithite	M
Grossularite	32
Guanajuatite	8?
Gummite	M
Gymnite	M
Gypsum	5
Hackmanite	I
Haidingerite	?S
Halite	32
Halloysite	M
Hambergite	8
Hancockite	5?S
Hanksite	27
Hardystonite	M
Harmotone	5
Hatchettolite	32?I
Hauerite	*28I
Hausmannite	*11I
Hauynite	*31I
Hedenbergite	5
Hedyphane	M
Heintzite	5
Hellandite	5
Heloite	*28?R
Helvite	*31I
Hematite	21
Hercynite	32
Herderite	8
Herrengrundite	5
Hessite	32
Hetaerolite	M
Heulandite	5
Hielmite	8?I
Hieratite	32
Hillebrandite	M
Hiortdahlite	2
Hisingerite	M
Hodgkinsonite	5?I
Hoeferite	M
Hokutolite	H
Holmquistite	5?HI
Hopeite	8
Howlite	M
Huebnerite	5
Humite	8
Hussakite	*13
Hutchinsonite	8
Hyalophane	5
Hydroboracite	5
Hydromagnesite	5
Hydrozincite	M
Hypersthene	8
Ilmenite	17
Ilminerutile	15
Ilsemannite	M
Ilvaite	8
Inesite	2
Iodembolite	32?I
Iodobromite	32
Iodyrite	*26?I
Iolite	8
Jadeite	5
Jamesonite	5?SI
Jarosite	21
Jeffersonite	5?I
Jenkinsite	M
Jezekite	5?
Johnstrupite	5
Jordanite	5
Joseite	M
Kainite	5
Kalinite	30
Kaolinite	5
Kasolite	I
Kelihauite	5
Kentrolite	8
Kermesite	5?SI
Kieserite	5
Klaprotholite	8
Klebelsbergite	?S
Knopite	32?I
Kobaltmanganerz	M
Koenenite	21
Koppite	32
Kornerupine	8
Krennerite	8
Kroehnkite	5
Kunzite	2

Labradorite	2
Langbanite	17
Langbeinite	*28A
Langite	8
Lanthanite	8
Lapis-lazuli	H
Laumontite	5
Laurionite	8
Laurite	*28
Lautarite	5
Lavenite	5
Lawsonite	8
Lazulite	5
Lazurite	5
Leadhillite	5
Lehnerite	I
Lehrbachite	M
Leonite	5
Lepidolite	5
Lepidomelane	H
Leucite	*31?I
Leucophanite	*6A
Leucophoenicite	5?I
Libethenite	8
Limonite	M
Linarite	5
Linnaeite	32?
Licroconite	5?I
Liskeardite	M
Lithiophilite	8
Loeweite	15
Loellingite	8
Loparite	I
Lorandite	5
Loranskite	8?
Ludlamite	5?I
Ludwigite	M
Magnesite	21
Magnetite	32
Magnetoplumbite	I
Malachite	5
Malacon	I
Mallardite	MI
Manganhedenbergite	5?I
Manganite	8
Manganophyllite	I
Manganosite	32
Manganotantalite	8?
Marcasite	8
Margarite	5?RI
Margarosanite	2
Margasite	5
Marialite	13
Marignacite	32
Marmolite	M
Marshite	*31I
Martite	32?I
Mascagnite	8
Matlockite	15?I
Maucherite	15?I
Meionite	15I
Melanite	32
Melanocerite	21
Melanophlogite	?SI
Melanterite	5
Melilite	15
Meliphanite	*9?A
Mellite	15
Mendozite	30
Menilite	M
Merwinite	I
Mesolite	5
Metacinnabarite	*31I
Meta Torbernite	I
Metavoltine	?SI
Miargyrite	5
Microcline	2
Microlite	32
Microperthite	?HS
Microsommite	?SI
Miersite	*31R
Milarite	27*
Millerite	*20I
Mimetene	25
Mimetite	25, 231
Minium	?S
Mirabilite	5
Mizzonite	13
Molybdenite	27
Molybdite	8
Monazite	5
Monticellite	8
Montmorillonite	M
Montroydit	8
Morensonite	6
Morganite	27
Mosandrite	5
Mossite	15
Mottramite	M
Muellerite	M
Muscovite	5
Muthmannite	*7R
Nadorite	8?I
Nagyagite	8
Natrolite	8
Natron	5
Naumannite	32
Nemalite	M
Neotantalite	32
Neotocite	M
Nephelite	*23I
Nephrite	M
Neptunite	5
Nesquehonite	8?I
Niccolite	*20I
Nickolsonite	8
Nickelbluete	5
Nickeleisen	32
Niter	8
Nocerite	21?SI
Northrupite	32
Noselite	*31I
Nowmeite	M
Ochrolite	I
Octahedrite	15
Okenite	M
Oligoclase	2
Olivenite	8
Olivine	8
Omphacite	M
Onofrite	31
Opal	M
Orpiment	8
Orthoclase	2
Osmiridium	21
Otavite	21
Ottrelite	2?I
Pachnolite	5
Pandermite	5
Paragonite	5
Parahoepite	2
Paralaurionite	5
Paratakamite	21?
Paravavxite	I
Pargasite	5
Parisite	21
Patronite	M
Pearceite	5
Pectolite	5
Penninite	5
Pentlandite	32
Percylite	32?I
Periclase	32
Peristerite	2
Perovskite	8?
Perthite	?H, S
Petalite	5
Petzite	32?
Pharmacolite	5
Pharmacosiderite	*31I
Phenacite	17
Phillipsite	5
Phlogopite	5
Phosgenite	15
Phosphoferrite	M
Phosphophyllite	5
Phosphosiderite	I
Phosphuranylite	M
Pickeringite	M
Picotite	32
Picromerite	5
Piedmontite	5
Pinakiolite	I
Pinguite	M
Pinite	M
Pinnoite	*10I
Pirrsonite	*7
Pisolite	M
Pitchblende	32
Plagionite	5?I
Plattnerite	15

Pleonast	32
Plumbojarosite	21
Polianite	15
Pollucite	?I
Polybasite	5
Polycrase	8
Polydymite	32?
Polyhalite	5?I
Polymignite	8
Powellite	13C
Prehnite	*7I
Priorite	8?I
Prismatine	8
Probertite	M
Prochlorite	5?I
Proustite	*20C
Pseudobrookite	8?S
Pseudomalichite	M
Psilomelane	M
Psittacinite	M
Ptilolite	?S
Pucherite	8
Pumpellyite	I
Pyroargyrite	*20I
Pyrite	30
Pyroaurite	21
Pyrochlore	32
Pyrochroite	*20?I
Pyrolusite	8?HI
Pyromorphite	25
Pyrope	32?
Phyrophanite	17
Pyrophyllite	8
Pyropissite	M
Pyrosmallite	I
Pyrostilpnite	5
Pyroxene	5
Pyroxmangite	2
Pyrrhotite	*20?C
Quartz	*18A
Quenselite	I
Quercyite	M
Quisqweite	M
Ralstonite	32
Rammelsbergite	8
Raspite	5
Realgar	5
Rhabdophanite	M
Rhodochrosite	21
Rhodolite	I
Rhodonite	2
Rhomite	2
Richterite	I
Richardite	M
Riebeckite	5
Rinkite	5
Rinneit	21
Ripidolite	5
Risorite	32?I
Riversideite	M
Romeite	32?I
Roscoelite	?S
Rosenbushite	5
Rowlandite	M
Ruby	21
Rumpfite	M
Rutherfordine	5
Rutile	15
Safflorite	8
Sal-ammoniac	*28
Salite	5
Samarskite	8
Sanidine	5
Sapphirine	5
Sarcolite	*10?I
Sartorite	5?S
Sassolite	2
Scheelite	13I
Schefferite	5
Schirmerite	M
Schizolite	2
Schorlomite	32
Schreibersite	M
Schrockingerite	8
Schrotterite	M
Schwartzengergite	?S
Schwetzite	*31
Scolecite	*4A
Scorodite	8
Semseyite	5?I
Senarmontite	32
Sepiolite	M
Serpentine	5
Serpierite	8?S
Shortite	*7A
Siderite	21
Sillimanite	8
Sipylite	*10I
Skemmatite	H
Skutterudite	30
Smaltite	*38I
Smithsonite	21
Sodalite	*31?I
Sodaniter	21
Spencerite	5
Spessartite	32
Sphalerite	*31A
Spinel	32
Spodumene	5
Spurrite	5?I
Staffelite	M
Stannite	*11I
Staurolite	8
Steenstrupine	21
Stephanite	*7RI
Sternbergite	8
Stibiconite	M
Stibiotantalite	*7A
Stibnite	8?I
Stichtite	I
Stilbite	5?
Stilpnosiderite	M
Stolzite	13
Strengite	8
Stromeyerite	8
Strontianite	8
Struvite	*7A
Sulfoborite	8?R
Sulfur	8 or 7
Sulvanite	M
Sussexite	M
Svanbergite	21
Sychnodymite	32
Sylvanite	5
Sylvite	*28I
Symplesite	?SI
Syndalphite	5?
Synganite	5
Tachyaphaltite	15
Tachyhydrite	21M
Talc	5
Tantalite	8
Tapiolite	15
Tarbuttite	2
Tasmanite	?S
Teallite	8?S, I
Tengerite	M
Tennantite	*31I
Tenorite	8
Tepbroite	8
Tetradymite	21
Tetrahedrite	*31C
Thalenite	5
Thaumasite	M
Thenardite	8
Thermonatrite	8
Thomsenolite	5
Thomsonite	8
Thorianite	32
Thorite	15
Thortveitite	8?I
Thuringite	M
Tiemannite	*31A
Tiger-eye	M
Tilasite	5?I
Titanite	5?I
Titanmagneteisen	32
Topaz	8
Topazolite	32
Torbernite	15
Tourmaline	*20A
Trecbmannite	17
Tremolite	5
Tridymite	32?I
Trimerite	2
Triphylite	5
Triplite	5
Triploidite	5
Tritomite	21?
Troegerite	5?
Troilite	M
Trona	5

Troostite	17	Variscite	8?S	Wollastonite	5
Tscheffkinite	M, H	Vauxite	I	Wulfenite	*10
Tschermigite	30	Vermiculite	I	Wurtzite	*20A
Tungstenite	M	Vesuvianite	15		
Tungstite	8	Villiaumite	32?I	Xanthoconite	21
Turgite	I	Vivianite	5	Xanthophyllite	5?I
Turquois	2	Volborthite	I	Xanthoxenite	5?S
Tychite	32	Voltaite	32?I	Xenotime	15
Tyrolite	M	Vonsenite	8?I		
Tysonite	27			Yttrialite	M
Ulexite	M	Wad	M	Yttrocerite	M
Ullmannite	30	Wagnerite	5	Yttrofluorite	32
Uralite	?HI	Walpurgite	2	Yttrokrasite	8
Uraninite	32	Warwickite	I	Yttrotantalite	8
Uranocricite	8?	Wavellite	I		
Uranophone	M	Wernerite	*10I		
Uranopilite	M	Whewellite	5	Zeratite	M
Uranosphaerite	M	Whitneyite	MI	Zaophyllite	I
Uranospinite	8?	Wiikite	I	Zeunerite	15
Uranotballite	8	Wilkeite	I	Zincite	*19?I
Uranothorite	M	Willemite	17	Zinkenite	8
Uranotile	2	Wilsonite	I	Zinwaldite	5
Utahite	?S	Witherite	8	Zircon	15
Uvanite	8?S	Wittichenite	8	Zirkelite	32
Uvarogite	32	Woehlerite	5	Zoisite	8
Valentinite	8	Wolfachite	8	Zorgite	M
Vanadinite	25I	Wolframite	5	Zunyite	*31AS

Of the 830 minerals listed 70 belong to classes that allow piezo-activity but only 17 are found to be active by the Giebe and Scheibe test. (Our test of Iodyrite was negative but Greenwood and Tomboulian[4] found it to be active; on the other hand, we found Scolecite to be active while they report it inactive.) It may be that others of the remaining 56 classes have such small piezo-electric constants as to be undetectable. Others may be incorrectly classified as to symmetry.

Of these active materials, quartz is the most important. Because of its excellent mechanical properties (stability, etc.) as well as for its relative cheapness it seems destined to remain one of the most important piezo materials.

Tourmaline is also important because of the high magnitude of its elastic moduli in certain directions; however, it cannot be obtained in large pieces of satisfactory homogeneity.

Sphalerite is very difficult to handle because of its many cleavage planes, and appears to give little promise of becoming practically useful. Its activity is quite marked.

Homogeneous crystals of calamine appear to be very rare, so that workable crystals large enough for ordinary piezo-electric application are unobtainable. Most of the material occurs massive.

[4] On Piezo Electricity—Greenwood and Tomboulian—Zeits. f. Krist. Jan. 1932.

Epsomite gives a marked response but the crystals are generally small and they do not weather well. There is some possibility, however, that they can be made artificially.

Boracite gives a marked response, but boracite alters slowly. Its impermanence may bar it for some uses.

Stibiotantalite occurs only in thin scales, and the necessary cuts must be made in the most wasteful way. Twinning is prevalent and the composition varies widely.

Scolecite occurs only as small crystals a few millimeters in diameter and a centimeter or so in length, uniformly twinned.

Iodyrite has been found to be active by other investigators. It is electrically conductive, very soft and not very common.

Struvite is soft, unstable, and occurs only in small crystals.

Zunyite occurs only in minute crystals.

Langbeinite slowly changes its crystal structure. It may be made artificially so may be of some use if it can be kept from alteration.

Leucophanite and Meliphanite are related minerals. Neither seems to occur in good (i.e., homogeneous and untwinned) crystals of usable size.

Wurtzite does not appear very active but *good* crystals were not obtainable.

Tiemannite crystals were also unobtainable, but fragments of massive tiemannite responded. Crystals might respond more energetically if they were obtainable, but minerals that are too difficult to get would not be of practical use.

Epistilbite occurs only in small specimens, uniformly twinned.

The mineral clinohedrite is strongly active but crystals are very rare.

Cronstedtite and Edingtonite are very weakly active. Crystals of these are very rare.